THE PIONEERING DAYS OF CT AND MRI

Between 1976 and 1987 I was fortunate enough to be working in the medical imaging business, and in particular during the pioneering days of CT (computed tomography) and MRI (magnetic resonance imaging). Today all of us are aware of CT and MRI scanners, and most of us will have been in one as a patient at some time or another. Yet how many of you know who invented them and how they came into use?

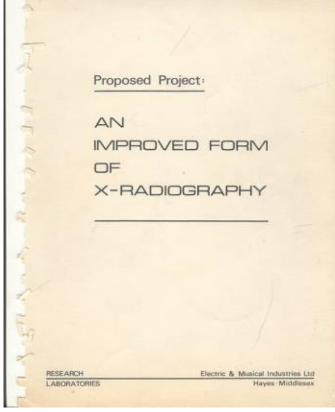
In 1976, I joined EMI Medical which was a newly formed EMI company developing and expanding a worldwide business on the back of a fantastic new invention, the CT scanner. But EMI was a music company, so how was it involved with CT? In fact EMI had a very skilled central research labs (CRL) at Hayes that had originally been set up under the Gramophone Company and His Master's Voice. And CRL had been heavily involved developing Radar during the war.

Within CRL was an individual engineer called Godfrey Hounsfield, who in a gap following a cancelled project, invented the CT scanner. Also EMI had gained a lot of income from its music business and in particular the Beatles and had money to invest; a great combination.

Godfrey Hounsfield was an engineer doing research in CRL. He was born in 1919 at Sutton-on-Trent, near Newark, the youngest of five children of a steelworker turned farmer. He attended Magnus Grammar School, Newark, but was not strong academically, and he left to work for a local builder. On the outbreak of war he volunteered for the RAF, where he was encouraged to study radio mechanics, and passed his first examination with such flying colours that he spent the rest of the war as an instructor. He received a Certificate of Merit for experimental work, and after the war he was awarded a scholarship to study for a diploma at the Faraday House Electrical Engineering College in London.

Later he joined EMI and found his way into CRL. And he was the clear inventor of the CT scanner. Some theoretical work was also done by Allan Cormack at the Groote Schuur Hospital in Cape Town and then at Tufts University in Massachusetts, but Godfrey was the first person to propose and put together a machine that could take CT image. He was a mild mannered genius and an absent minded boffin. Later he was awarded the Nobel Prize and a knighthood. He died in 2004.

Godfrey felt that conventional X-ray, as a simple shadowgraph system, wasted much valuable information. Conventional X-ray is basically a shadowgraph technique only showing a difference between the soft and hard tissues in the body. The first X-ray was taken by Rontgen in Germany in 1895, an image of the hand of Frau Rontgen.



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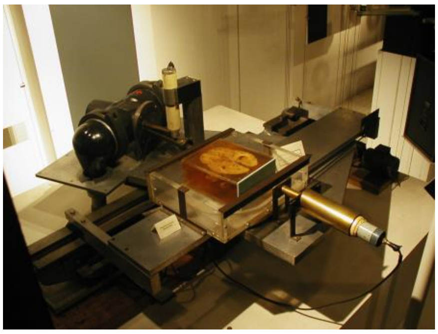
Even today conventional X-rays have limitations, tissues behind bone cannot be seen at all, and it is difficult to differentiate between soft tissues. Imaging the brain surrounded by the skull is particularly difficult using conventional X-rays. Godfrey felt there was a way of getting more from X-rays, so he wrote a short paper outlining a technique that he called Computed Axial Tomography, later shorted to Computed Tomography or CT. The paper was not very long and the drawings were just sketches, but even so EMI gave him the go-ahead.

He produced a simple rig to prove that the Computed Axial Tomography arrangement could work in practice, namely a lathe bed to mount an X-ray

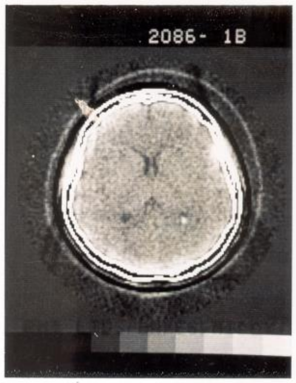


tube and a detector each side of a specimen, and moved the tube by hand. He used as a specimen a preserved pig's brain in a Perspex box. The X-ray tube directed X-rays through the pig's brain and the detector measured the level of the X-rays coming through the sample. This reading was digitised and put into a computer memory. He then moved the tube and detector by hand and took another reading. Having taken a large number of readings, he then processed the collected data on the CRL big mainframe computer to make a cross sectional image of the pig's brain.

After approval and some funding from the Department of Health the first working machine was built and installed at the Atkinson Morley Hospital in Wimbledon.

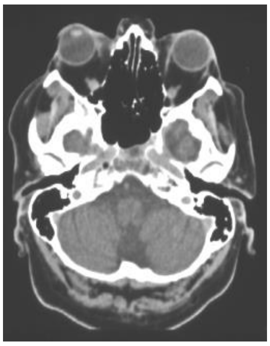
A civil servant in the Dept. of Health, Gordon Higson, and John Powell, Group MD of EMI, recognized the significance of the invention and were careful about selection of the Atkinson Morley. They wanted to quietly prove that the machine could produce useful pictures of real patients before it went any further. They wanted to keep things under control.

In October 1971, the first individual to benefit from a CT scan was a woman with a suspected brain lesion. Much good work was done at Atkinson Morley by Dr Ambrose, imaging patients' heads, to demonstrate the effectiveness of the scanner Early head scanners used a water bag; the patient put his or her head in a giant condom so the head was effectively surrounded by water.



Taking one slice at a time and taking some minutes for a complete scan, the data was taken to the CRL mainframe computer and processed overnight to get an image. This first CT from the Atkinson Morley Hospital is with the London Science Museum.

The scanner was for heads alone at this stage. For the first time the cross section of a living person's brain could be seen with contrast between the various tissues of the brain. The pictures were viewed on an old style Cathode Ray, or were put onto an X-ray film and viewed on a light box. Sometimes also recorded on a Polaroid film, which were used a lot in the early days



Initially, scanners worked on as little as 64 x 64 pixels but today has much higher resolution. As time went on the image quality got better, and by the end of the 70s the blurry images of the first scanners had been transformed into high-resolution cross-sections of much better fidelity, but still nowhere near the image quality and detail of today.

The first that EMI told the world of neuroradiology about this invention was at the British Institute of Radiology in April 1972 and later that year it was announced at the large international radiology meeting in the USA. Immediately acclaimed all over the world, every radiologist wanted one
The ones with money available were the first to get them. The private clinics in the USA who could raise investment capital quickly were the first to put in orders for significant numbers of units, particularly in California.

EMI decided to build a new business on this technology, and as things went on it decided to set up direct operations in all the major countries of the world. By this I mean that we established subsidiary companies and recruited our own local staff, rather than use distributors or tie up with an established company. EMI took advantage of this success and quickly built up a worldwide business taking on the major companies in the medical technology businesses, such as GE (USA), Siemens, and Philips. We recruited staff worldwide for sales and support of units sold throughout the world. New factories were established at Hayes, and Radlett in the UK and a major facility in the USA. It became a huge success story.

The CT principle of the head scanner was enlarged to make a full body scanner. The same principle was scaled up and made bigger with room to fit the human body. Cross-sectional slices of the body could now be taken. The final product was much more than just this scanner unit, the whole system included a rack of electronics, a mini-computer, a control and display console, high voltage X-ray equipment and, of course, the software to collect the data and reproduce and display an image. The techniques rapidly developed to get the maximum image quality and diagnostic usefulness.

The first body scanner was installed at the Northwick Park Hospital at Harrow, where a lot of the early body scanning work was done. This is an early picture of that unit, dated 1976, some 44 years ago. The images were much more useful than conventional X ray for diagnosing diseases in the body, because it could distinguish between soft tissues, for example it could distinguish cancers or tumours which are only slightly more opaque than the surrounding soft tissue.

And the collection of bits and pieces that came from the factory in the early days was a long way from being a useful medical tool that could be used by hospital staff in a hospital environment. Furthermore in those days, hospitals staff, radiographers and radiologists, were completely unfamiliar with this type of equipment and they needed a lot of support, so we had a team of radiographers who trained and worked with the hospital staff for the first two weeks or so.

Deliveries were all over the world, and we were setting up local technical capability. We could not produce the systems fast enough and the number of units ordered, and installed, surpassed all expectations. Initially expected to be confined to a few specialist centres, but in reality, demanded by a much wider group of hospitals.

X-rays coming from an X-ray tube to one side are measured by the detectors on the other side of the patient. The amount of absorption of the X-rays as it passed through the body being the difference between the readings at each detector and the reference detector that has nothing in its path. The readings are converted into a digital number and stored in the computer.

As the tube moves around the body many readings of the value of the absorption of a variety of paths at various angles through the body are taken. The computer does a clever mathematical calculation whereby knowing the absorption through many paths it can calculate the x-ray absorption value of each individual pixel of an image. A grey scale, or a colour scale can then be applied to produce an image of the insides of the body.

The more modern CTs are developments and improvements from the original, rather than any basic change. The basic technology is the same and they have a more modern look. Modern CTs can use a spiral scan sequence whereby as the X-ray tube circles the body, using slip rings. The patient lies on a table which motors the body through the scanner. A very fast scan can be obtained this way.

But the greatest advances have been with the storage and speed of the modern computer, and the more sophisticated software that goes with it. Today either by using a spiral scan or by the scanning of multiple slices and then putting them together, you can get a set of values of a solid area in 3 dimensions. And by applying colours to these values in a clever way you can produce the most amazing pictures.

And the business continued to be fun for some time. We successfully recruited and trained teams of engineers in many countries, but often we installed the first scanners using staff from the UK. And in the more difficult countries of the world we continued to use UK engineers. We had some interesting challenges; Bangkok, Athens, Montevideo, Moscow etc. In Japan we co-operated with Toshiba and their medical division at that time was a very traditional Japanese company. Establishing ways of working across the cultures was a fascinating challenge.

The NHS, like many big health systems around the world, found it difficult to produce money quickly to purchase these new expensive machines. Charities stepped in and quickly raised the money and ordered a unit. But the equipment required specially prepared rooms and in the days before the NHS were outsourcing and contracting out the hospitals were very slow in providing these rooms. The scanner could be produced with no rooms ready to install it and had to go into store. We started to take on the whole job, establishing a site planning department, project managing, using sub-contractors to prepare the rooms and facilities to enable our team to install the scanner, train the staff, and kick start the supplies of consumables.. It was a new venture for us and for our customers.

This growing new market attracted many new entrants. Small companies reacted quickly to produce a scanner sometimes of dubious effectiveness. The established imaging companies spent large sums of money trying to develop a scanner. After all EMI was challenging the position of established giants in medical imaging equipment such as GE, Siemens, Phillips.
Although EMI had a good patents department and applied for a number of patents, this did not prevent the appearance of competing machines. CT scanners were becoming 'must-have' pieces of equipment, but this was seen as placing strains on hospital budgets. The US government therefore introduced the requirement for a certificate of need to control the number of applications for new scanners. Any hospital or clinic had to get a certificate from the federal government before they could place an order. And initially the certificates were very slow in arriving.

Some, including John Read the chairman of EMI at the time, noticed that the Certificate of Need was introduced when the big influential American company GE had yet to produce a working system, effectively delaying orders and giving them time to develop a scanner. And the number of certificates increased as soon as they had produced a system. This initially had the effect of halving the scanner market. EMI was beginning to have difficulties in other parts of its business, notably music, and its share price started to come under pressure, making it a take-over target
In 1979, EMI was sold to Thorn. The new Thorn-EMI immediately rationalised and sold off the CT scanner business to GE at a knockdown price.

EMI had also been quietly developing Magnetic Resonance Imaging. EMI did not invent the MRI scanning technique but was doing some excellent work developing what was to become the first commercial machine. The work was partly funded by the Department of Health who would not allow the research to go to an overseas company. So Thorn had to sell the MRI part of the business to the UK's GEC and it became part of the medical technology company that GEC was establishing at the time, called Picker International.

Once again it was a relatively unknown British genius who invented MRI, Dr Peter Mansfield. He came from humble beginnings in South East London, attending a secondary school in Peckham. He left school at 15 and became a printer. He took A-levels at night school and studied physics at Queen Mary's

College, London, graduating with a BSc in 1959 and a PhD in 1962. He won the Nobel Prize in 2003 and was knighted for his achievements with MRI.

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MRI is a type of nuclear magnetic resonance (NMR), which is used by chemists in the laboratory to study the properties of molecules. Mansfield's developments in the 1970's showed that NMR techniques could be used to produce images of the body. Mansfield demonstrated how the radio signals from NMR can be mathematically analysed, making the signals into a useful image. He is also credited with discovering how fast imaging could be possible by developing an MRI protocol called echo-planar imaging, which allows images to be collected many times faster than previously possible. This made functional MRI feasible and practical.

Dr Peter Mansfield developed a working unit at Nottingham using an electro-magnet at normal temperatures which did not have a very high magnetic field, namely 0.1 Tesla. The original machine is also in the London Science Museum.

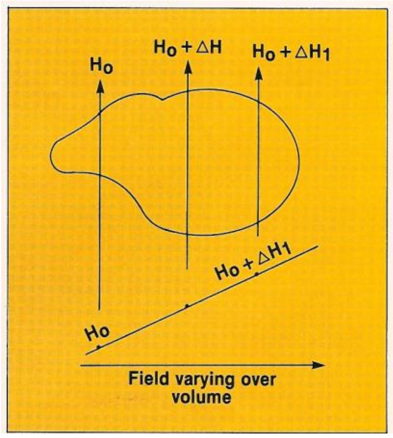
The unit at Hammersmith Hospital inherited by GEC Picker from EMI used a cryogenic magnet of a higher magnetic field. A cryogenic magnet is one where the electrical coils are cooled by liquid helium to very low temperatures where the coils ore superconducting and very high currents can be maintained. Indeed it is the forerunner of many modern machines and has a doughnut shaped scanner which may look a little similar to a CT but it works on an entirely different basic principle, even though it is similar to CT in that it produces high resolution images of the inside of the body, including the brain.

MRI is also like CT in that a tomographic imaging technique - "tomo" means slice - it produces an image in thin slices through the body. Also the client is placed inside a scanner that is made up of a moveable couch inside the large magnet, and the pictures are made up of pixels displayed on a computer screen.

The magnet consists of stationary coils of thick cable designed to create a very intense magnetic field, between 1.5 and 4 Tesla (1.5 tesla is 30.000 times greater than the earth's magnetic field). Strong enough to accelerate a paper clip to dangerous speeds across the distance of a small room! In order to generate fields of this intensity the coils are usually superconducting, and to achieve this they are cooled by liquid helium to near absolute zero temperatures. The magnetic field has to be accurate in strength and consistency, so there are shim coils and gradient coils, additional coils to adjust and alter the exact value of the field at any point in the imaging volume. There is no mechanics in an MRI, the thumps that you hear as a patient are the coils moving when they are switched on and off.

Most MRI images are obtained using the water in the human body. The human body is almost 65% water. MRI uses the properties of the proton within each hydrogen atom in the water. Each of these protons spins about an imaginary axis like a spinning top that makes the proton act like a very small magnet. In everyday situations the protons in the body spin at random angles, but when the body is placed in a high magnetic field the spins all line up in one direction. Then a radio frequency pulse, from another special coil in the magnet, is directed at the area of the body that is to be studied. An RF pulse after all is a time varying magnetic field. This radio pulse stimulates the protons in that region and, once the pulse is switched off, the protons relax back into the alignment that they were in before the RF was turned on.

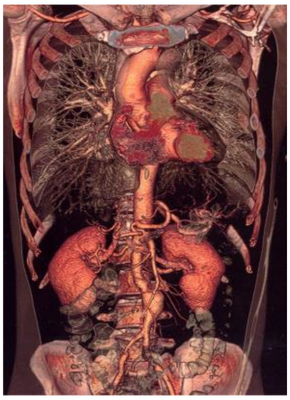
Another coil, usually placed close to the body works as an aerial, and detects the radio signals as the proton relaxes. The behaviour of the signal after the radio frequency pulse is switched off is influenced by the type of tissue that the proton is in, so the computer software can analyse the signals and build up information on the different types of tissue.



Some additional coils, namely the gradient coils, apply a small gradient to the value of the field in a particular direction is made to vary linearly along that line. It is a small variation compared to the strength of the main field but enough to make a difference to the frequency of resonance of the protons.
So by accurately measuring and analysing the frequency of the RF response, the computer knows where along the gradient the response is coming from. By using a set pattern of different gradients in a scanning sequence, the computer can determine which relaxation signature corresponds to which pixel of the image that it creates. From the nature and time of the relaxation it knows the type of tissue in that pixel, and can build up a picture.

Graphical processors are used to reconstruct and display images quickly. Modern MRIs have taken advantage of software developed for the computer gaming industry and can do remarkable things with the images.

Modern MRI images are very good quality and can be displayed and manipulated. For example, you can take a journey through the blood vessels and see what is there. The volume being imaged can be quite large and slice images can be combined to get a larger view. Colour can also be applied in a way to help diagnosis from the image



Going back to the early days installing and getting MRI systems to work we had many challenges. In many ways more difficult than CT, for example, issues of getting RF signals at low energies to behave in a way that you wanted them to work.
But with a 5-tonne cryogenic magnet not all the challenges were highly technical. Some were very practical
We sold a unit to the hospital then called the National Hospital for Nervous Diseases at Queen's Square in London, and they wanted it in a basement, down some narrow stairs
The only way we could get it there was by lifting the unit over the building, and lower it down a void down inside the building
We had to lift it over the roof and down a blind shaft and then move it sideways when it got there. We were not used to this type of problem so we employed Taylor Woodrow to do it for us. An straightforward job for them.

One of the more interesting jobs was at Mount Vernon Hospital in Northwood, where we built a complete new scanner suite equipped with CT, MRI, and a specialist 3-axis X-ray unit. Another high profile installation was at the Manchester University Medical School. We struggled with issues of getting the right RF responses, in spite of all the preparations and predictions, the behaviour of the radio frequency responses varied with the location and surroundings of the machine. And the unit at Manchester was particularly tricky. Professor Isherwood was getting very nervous that we would ever get it working properly, but eventually it was working well and his team made some significant advances.

In 1987 I moved out of the medical imaging business and onto network communications. Shortly afterwards Picker was broken up and MRI moved to Philips and other parts of the business went to GE. So today there are no British companies involved. Cryogenic magnets are still made in Oxford but owned today by Siemens. The survivors are the American GE, Philips, and Siemens and Toshiba., big companies with long-term strategies. So it was a disappointing end for the business in the UK

But nonetheless a great deal of good has come from CT and MRI, with thousands of scanners throughout the world. Millions of patients have benefitted from the results of a CT or MRI scan. Over the years there has been a quiet revolution in medical practice as a result. The diagnosis and management of disease has changed, and techniques involving intervention can be performed with the minimum of invasion.

It was British engineers who were the inventors of these technologies. It was British Hospitals who first used them and who showed how they could be used in medicine. This is yet another area where engineers in the UK have led the world only to find some years later we are no longer in the game. In this case I don't think it was for the want of trying.

Anthony Bayly
29 April 2020